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CHARGE DISTRIBUTION OF HEAVY NUCLEI OF COSMIC RAYS RAYS IN THE REGION z $\geq$ 26

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CHARGE DISTRIBUTION OF HEAVY NUCLEI OF COSMIC RAYS IN THE REGION $Z \geq 26$

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ABSTRACT. The photoemulsion method is used to study the charge composition of heavy primary nuclei. Exposure was performed at 300 km outside of the magnetic field of the Earth. Study of the exposed emulsions is being continued.

Investigations of the charge spectrum of primary cosmic rays may provide substantial data on the processes of cosmic ray generation in sources and on the conditions of their propagation in space. Of special interest in recent years is the study of the charge distribution in the region of large charges $Z \gg 26$. /2255*

Available data [1 - 4] on the relative content (for the Fe group) of heavy nuclei with $Z > 26$ have been studied little and agree poorly with one another. Thus, for example, the relative contents of nuclei with $Z \geq 48$ according to the data in [2, 4] differ by two orders of magnitude.

Quite interesting and worthy of discussion are the results obtained in the work of Fowler et al. [4] in which it was shown that in primary cosmic rays nuclei are encountered with $Z \sim 90$, and according to later investigations by these authors [5] even nuclei with $Z \simeq 110$.

We set up experiments for studying the charge composition of heavy primary nuclei with $Z > 26$ using a photoemulsion method. Exposure of the emulsion stacks was carried out at an altitude of 300 km (the satellite "Kosmos-213" and the space ship "Soyuz-5") and outside the magnetic field

*Numbers in the margin indicate pagination in the original foreign text.

of the Earth (automatic interplanetary [AIS] "Zond-5"). We assumed that it is necessary to set up an experiment for which we could investigate each particle of interest to us in a significant segment of the range in the emulsion ($\sim$ 10 cm and higher). Then the investigation of particle ionization on the entire segment of the range permits us to separate the particles, which are strongly ionized due to the low velocity, from the particles whose ionization is caused by the large charge. Let us note that during exposure on the satellites there is no sharp limitaion in hardness of the primary cosmic particles penetrating into the emulsion.

Furthermore, with penetration into the emulsion of very heavy nuclei ($Z > 90$) we must have cases recorded of fission accompanying the nuclear interactions. This would be convincing proof of the existence of heavy nuclei. Thus, the possibility of investigating the properties of particles on a large segment of the range in the emulsion ($\sim$ 40 $g \cdot cm^{-2}$) strongly increases the reliability of their identification.

At an altitude of 300 km, two emulsion stacks were exposed and one emulsion stack was exposed outside the magnetic field of the Earth.

On the satellite "Kosmos-213", a 2-liter stack was exposed, made of layers of the relativistic emulsion BR-2. The thickness of each layer was 400 μm. The duration of the exposure was 120 hours. On the spacecraft "Soyuz-5" a 1-liter stack was exposed. The emulsion was BR-2 (relativistic) and A-2 (sensitivity of 70 MeV per proton). The thickness of the layers was 400 μm. The duration of exposure was 72 hours.

Outside the Earth's magnetic field a 3-liter stack was exposed. The emulsions were A-2 and Ya-2. The thickness of the layers was 400 μm. The duration of exposure was 162 hours.

The absorbing layers over the emulsion stacks were of different thickness in the various experiments — from 0.6 to 3 $g \cdot cm^{-2}$.

The stack during each exposure was arranged in such a way that the primary cosmic particles, perpendicularly intersecting the minimal absorption layer over the stack, had a small angle of track inclination in the emulsion layers and their range in the chamber was ~ 10 cm.

To determine the size of the particle charges, we designed a semi-automatic photometer [6], which permits investigating the density of the track blackening.

To obtain a profile of the track blackening we used a system with an analysis slit and a plane-parallel rotating prism. As the parameter characterizing the charge, we selected the blackening profile. The instrument also permits measuring the part of the profile caused only by the δ-electrons which gives another independent means of determining the charge. The measurement accuracy of the area was 1%.

The charge graduation of the instrument showed that in the charge interval of $Z = 12 - 40$, the total profile areas of the optical darkening of the tracks of particles with different charges with an accuracy of 2% are directly proportional to the size of the charge. On the other hand, the areas of blackening caused only by the δ-electrons of a given energy range, are proportional to the square of the charge.

Thus, the charge of an unknown heavy particle was determined by two independent methods from relative measurements of optical blackenings, caused by this particle and nucleus of a known charge ($Z = 26$), at identical particle velocities.

The exposed emulsions are being investigated. Let us give certain preliminary data.

Evaluation of the Flux of Nuclei of the Fe Group at an Altitude of 300 km and Outside the Earth's Magnetic Field

To determine the composition of the particle flux incident on a certain area S, facing the surface with the absorption layer of minimal thickness, all the primary particles included in a given interval of solid angles having an ionization corresponding to the ionization of the relativistic nuclei of Fe and greater were registered. This was accomplished in the following manner. For a certain part of the emulsion stack in each emulsion layer we carefully examined in a microscope having a large magnification (900 x) the narrow band (5.5 mm in width) at the input of the primary cosmic rays into the stack, and registered all particles with the corresponding ionizations having a track inclination in the emulsion of $\leq 22°$. Each such particle was traced further in the emulsion and analyzed. As a result for each experiment we evaluated the number of nuclei in the Fe group, incident on the area S at a solid angle Ω for a time T.

We obtained the following values of the fluxes.

(1) At an altitude of 300 km: $F = 0.23 \pm 0.04$ particles$\cdot m^{-2} \cdot ster^{-1} \cdot sec^{-1}$ for the Fe nuclei with $E \geq 180$ MeV$\cdot$nucleon^{-1};

(2) Outside the Earth's magnetic field: $F = 0.33 \pm 0.05$ particles$\cdot m^{-2} \cdot ster^{-1} \cdot sec^{-1}$ for the Fe nuclei with $E \geq 150$ MeV$\cdot$nucleon^{-1}.

Evaluation of the Relative Content (for the Fe Group) of Heavy Primary Nuclei with $Z \geq 30$, $Z \geq 40$, etc.

Depending on the size of the charge from which we wish to begin registering the particles, in analyzing the emulsion we used various methods.

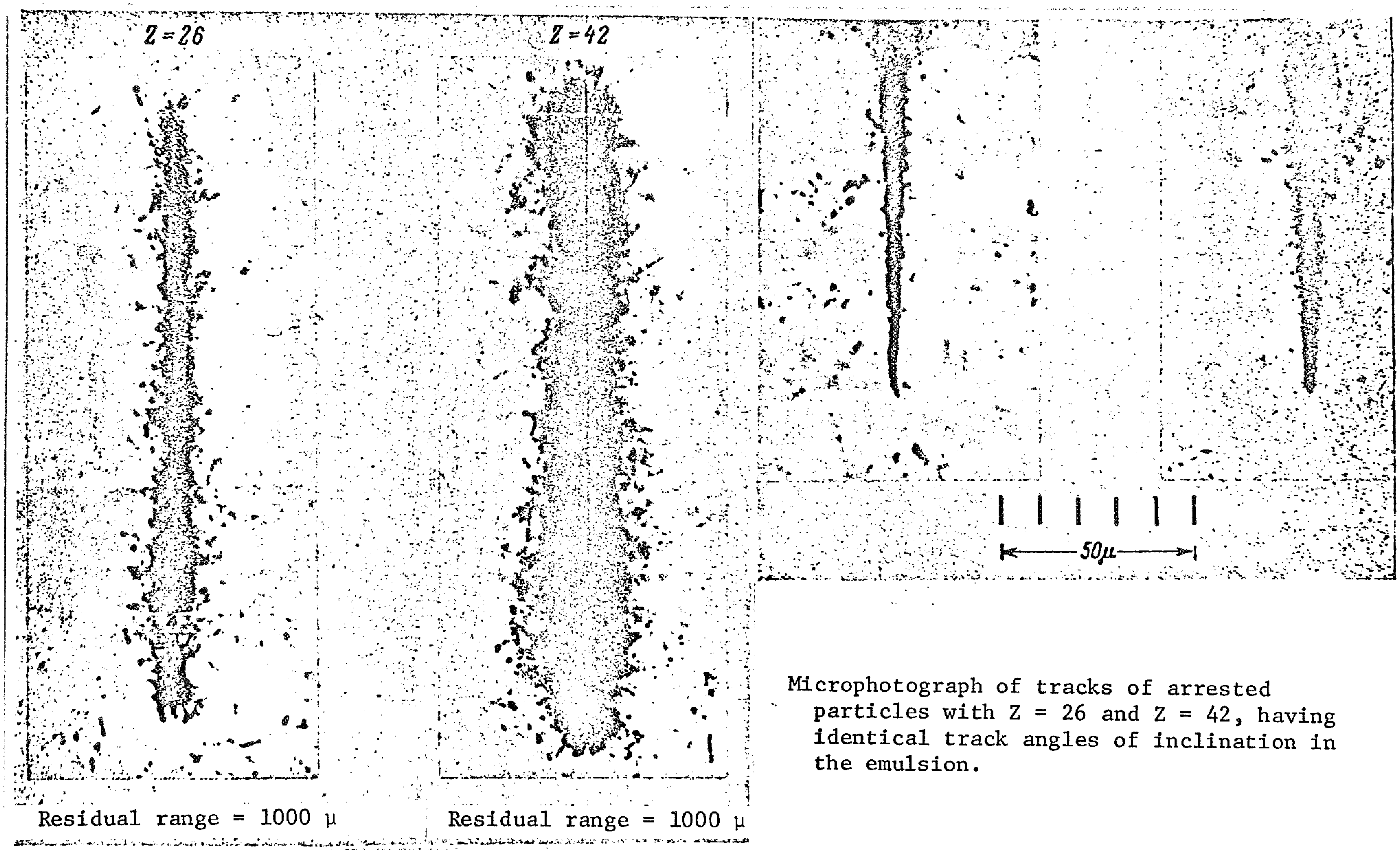
(a) To expose nuclei with $Z \geq 30$, the emulsions were analyzed by the same method as that used in determining the composition of the flux — with /2257 the aid of a microscope having a large magnification. In each emulsion layer we analyzed the narrow band (0.5 mm wide) at the input of the primary cosmic particles into the stack. We registered the particles with ionization corresponding to the ionization of the relativistic Fe and higher, with track angles of inclination in the emulsion $\leq 22°$. Each particle was traced further and analyzed. Using this method we analyzed the part of the stack exposed at an altitude of 300 km. We detected eight particles with $Z \geq 30$. The charges were determined with the aid of a semiautomatic photometer. We evaluated the number of nuclei with $Z \gtrsim 26$, incident on one and the same area in one and the same interval of angles, $N_Z \gtrsim 26 = 1395$.

(b) To expose nuclei with large charges ($Z \geq 26$) we used another method of analysis. Each emulsion layer was analyzed at the entry point of the cosmic particles with the aid of a microscope with small magnification (25 X). We registered the particles of interest to us in the interval of angles 2π; these particles were further traced in the emulsion and investigated. Thus, in analyzing the stack exposed on the satellite "Kosmos-213", we registered and analyzed particles with ionization corresponding to the ionization of relativistic nuclei with $Z \geq 40$. We detected two particles with $Z = 40 \pm 1$ and $Z = 42 \pm 1$. The number of nuclei of the Fe group incident on this same area in the same interval of angles, according to our evaluations, equals $\sim 1 \times 10^4$.

The microphotographs (see inset) give the tracks of the arrested particles with $Z = 26$ and $Z = 42$, having identical track angles of inclination in the emulsion.

The stack exposed on the spacecraft "Soyuz-5" and a small part of the emulsion exposed on the AIS "Zond-5" were analyzed for the purpose of determining the nuclei with $Z \geq 50$.

Analysis of the stack exposed outside the Earth's magnetic field is still not finished. Approximately 60% of the area of the input of the cosmic



Microphotograph of tracks of arrested particles with Z = 26 and Z = 42, having identical track angles of inclination in the emulsion.

particles was analyzed for the purpose of detecting very heavy nuclei ($Z \geq 70$). Not a single such nucleus was detected.

For each analyzed part of the input of the cosmic particles, we evaluated the number of incident nuclei of the Fe group in the investigated interval of angles.

On the basis of the available data, we obtained the relative content (for the Fe group) of nuclei with $Z \geq 30$, ≥ 40, etc, which are shown in the last graph of the table. For nuclei with $Z \geq 48$ and $Z \geq 70$, we give the upper limits of the values. The first columns give the data of other authors [1, 2, 4]. Let us mention that reference [1] gives the relative content of the heavy nuclei in the group with $Z \geq 15$.

From the table it follows that the data obtained in the present paper do not agree with the results of Bolodichev et al. [2]. The relative amount (in the Fe group) of nuclei $Z \geq 40$ and $Z \geq 48$, given in reference [2], are two /2258 orders of magnitude greater than the values obtained in the present work.

Along with this, our data do not contradict the results from the work of Fowler et al. [4]. Let us mention only a slight difference in the relative amount of nuclei with $Z \geq 40$.

RELATIVE CONTENTS OF NUCLEI

Z	$N_Z/N_{Z\geqslant 15}$, [1]	$N_Z/N_{Z\geqslant 21}$, [2]	$N_Z/N_{Z\sim Fe}$, [4]	$N_Z/N_{Z\sim Fe}$, present work
$\geqslant 30$		$3{,}8\cdot 10^{-2}$		$5{,}8\cdot 10^{-3}$
$\geqslant 30 \div 40$	$<1 \div 3\cdot 10^{-4}$			
$\geqslant 40$		$1{,}5\cdot 10^{-2}$	$4\cdot 10^{-5}$	$2\cdot 10^{-4}$
$\geqslant 48$		$4{,}0\cdot 10^{-3}$	$2{,}5\cdot 10^{-6}$	$<4\cdot 10^{-5}$
$\geqslant 70$			$1\cdot 10^{-6}$	$<1{,}7\cdot 10^{-5}$

Study of the exposed emulsions is being continued in the following directions: (a) further analysis and searching for heavy nuclei; (b) a detailed investigation of the charge distribution in the region $Z \geq 26$ and; (c) study of the energy spectra in the low energy region for particles with charges of different size at an altitude of 300 km and outside the Earth's magnetic field.

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